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Elucidating the role of governance in the development of the artificial intelligence technological innovation system in iran

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ABSTRACT

The Fourth Industrial Revolution has established Artificial Intelligence (AI) as a critical determinant of national competitiveness, necessitating a transition from linear innovation models toward dynamic Technological Innovation Systems (TIS). This study investigates the AI ecosystem in Iran from 2015 to 2025, revealing a systemic evolution from a "laissez-faire" approach toward a "developmental state" model. Method: Employing a qualitative descriptive-survey methodology, 20 in-depth interviews with key stakeholders were analyzed to elucidate the structural coupling between four governance functions—policymaking, regulation, facilitation, and service provision—and TIS dynamics. Results: The findings indicate that while effective policymaking and regulation have fostered maturity in knowledge development and legitimation, the ecosystem faces a critical bottleneck in resource mobilization, particularly regarding hardware infrastructure and human capital. Currently, the system relies heavily on the state's service provision function to compensate for market failures and international sanctions, highlighting the inherent fragility of the private sector. Conclusion: Consequently, this paper argues that governance must shift from a "direct provider" to a "financial facilitator" to ensure systemic sustainability. The research concludes by proposing strategic solutions, including leveraging technological diplomacy through alliances like BRICS to mitigate hardware constraints, establishing regulatory sandboxes for agile experimentation, and creating regulated data markets to stimulate private demand. By bridging the theoretical gap between governance and innovation systems, this study provides a localized framework that offers generalized insights for other emerging economies seeking to balance technological sovereignty with the structural and geopolitical constraints of the Global South.

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1. Introduction

The emergence of the Fourth Industrial Revolution has transformed previous development paradigms and positioned digital technologies as the central focus of national competitiveness (Hassane Zaoui, 2026; Kraus, 2022). In this context, Artificial Intelligence (AI) acts not merely as a technical tool, but as a "General Purpose Technology" (GPT) technologies possessing the potential to alter the entire economy (Grudinina, 2023; Raju, 2024) playing the role of a primary catalyst in the reconfiguration of economic and social structures. A proper comprehension of this research requires recognizing the transition to the era of "Cyber-Physical Systems" (CPS) (Castro, 2019), where the convergence of critical infrastructure with deep learning algorithms has elevated the dependency of governance systems on data to an unprecedented level.

Despite the transformative capacity of this technology, its development possesses a dual nature. The primary motivation of this research is to address concerns arising from the gap between the "pace of technological growth" and "regulatory capacity" (Lawn, 2020). In the absence of data-driven governance, risks such as "algorithmic bias" (Herzog, 2021), the lack of "interpretability" in black-box models, and ethical challenges will threaten public trust. Global experience indicates that managing these complexities necessitates a transition from linear models toward the establishment of a dynamic "Technological Innovation System" (TIS) (Anser et al., 2020; Kao, 2019).This ontological transition toward non-linear approaches remedies the inherent inadequacies of classical linear models specifically their neglect of the reciprocal dynamics between structural and functional components in technological development (Srivastava, 2025).

Studies on Technological Innovation Systems (TIS) indicate that these systems possess a non-linear and dynamic nature, subject to feedback loops and external factors. A TIS is defined as a "socio-technical system" whose ultimate objective is to facilitate the processes of generation, diffusion, and utilization of a specific technology or a defined technological field (Lundvall, 2010). To properly comprehend the functioning and success of these systems in the development of emerging technologies such as Artificial Intelligence, researchers have identified a set of key functions whose interaction is essential. These functions encompass "knowledge development and diffusion" through research and networking, "entrepreneurial experimentation" in the form of pilot projects and incubators, "guidance of the search" via policymaking and regulation, and "market formation" through standardization and demand stimulation. Furthermore, the sustainability of the system requires "resource mobilization" regarding financial and human capital, "legitimation" and social acceptance, and finally, the "development of positive externalities" such as knowledge spillovers and complementary infrastructure, thereby providing the necessary foundation for technological growth (Bergek, 2008; Hekkert, 2007; Palacios-Marqués, 2026; Wang, 2010).

Within this analytical framework, although determining technological boundaries constitutes the point of departure, this demarcation must not lead to reductionism or the unjustified privileging of a specific sector; the concept of technology encompasses a broad spectrum ranging from abstract knowledge domains to concrete products, and the system's structural architecture possesses the capability to be defined and evaluated across multiple spatial (national, regional) and sectoral levels (Schissler, 2024).

The focus of this investigation is the AI ecosystem in Iran, a context where purely technical analyses appear insufficient to elucidate the status quo. The fundamental challenge in this setting is the misalignment between key processes of the innovation system (such as knowledge diffusion and legitimation) and policy instruments. This research argues that the missing link in this ecosystem is the absence of a coherent "Meta-governance" framework (Hartley, 2013; Sørensen, 2016). The hypothesis of this study posits that by transitioning from the traditional role of the state to the fourfold functions of "adaptive policymaking"(Nellutla, 2024), "smart regulation" (Emilkamayana, 2021; Refaei, 2024), "ecosystem facilitation" and "provisioning" (Pascoe, 2025), it is possible to overcome institutional lock-ins. Subsequently, this article first elucidates the theoretical foundations of smart governance, then critically analyzes the situation in Iran, and finally proposes a framework for striking a balance between innovation and ethical considerations.

1.1. Theoretical Background

In recent years, the adoption of non-linear approaches to innovation has become increasingly prevalent, thereby remedying the deficiencies of linear approaches that neglected the impact of interactions between structural and functional components in technological innovations. Artificial Intelligence (AI) constitutes a transformative technological innovation that, beyond extensive technical interactions within an ecosystem, is significantly influenced by institutional and external factors such as data governance and technology ethics. Subsequently, concurrent with a review of concepts pertaining to the systems approach appropriate for the AI ecosystem, the necessity of the role and position of governance in the development of this technology is elucidated (Abdelgadir Mohamed, 2024; Bessen, 2022; Ojo, 2024; Rojas, 2022).

1.1.1 Definition of Technological Innovation System

A Technological Innovation System (TIS) is defined as a socio-technical system whose primary objective is the development, diffusion, and utilization of a specific technology or a field of technology (Lundvall, 2010; Nevzorova, 2022; Wandera, 2021). Although in this approach, defining the technological field and innovation serves as the point of departure for system analysis, this does not imply that a specific sector is considered more important than other sectors (Godin, 2020; Klerkx, 2021; Schissler, 2024). In this context, technology may refer to a knowledge domain (such as Machine Learning or Natural Language Processing) or a product with specific applications (such as autonomous vehicles). Furthermore, research indicates that the structure and functions of a TIS can be defined within various geographical boundaries, including national, regional, or sectoral levels (Antonenko, 2020; Asheim & Isaksen, 2002).

The structural dimension of a Technological Innovation System is described by its constituent components, comprising "knowledge and algorithms," "actors," "networks," and "institutions."

Although actors may operate individually, the prevailing approach posits that innovation systems are networks that interconnect and coordinate actors, internal knowledge, and resources (such as big data and computational power)(Carlsson & Stankiewicz, 1991; Liu & Tsai, 2021; Perini, 2009). Specifically, innovation in the field of Artificial Intelligence is a collaborative process encompassing a wide spectrum of actors at various levels, ranging from major technology firms and startups to universities, the public sector, non-governmental organizations, and ethical regulatory bodies. These actors interact with the AI ecosystem in diverse roles, such as data providers, algorithm developers, users, or policymakers (Anastasia et al., 2024; Yasmin, 2024).

Ultimately, knowledge, products, actors, and networks are all influenced by and situated under "institutions." Institutions shape interactions in the form of social constraints, legal requirements, or the "rules of the game" (Borjas, 2000; North, 1996; Ocasio, 2023). The structural components of the system possess reciprocal and intertwined relationships; this implies that actors and networks shape and advance institutions (such as privacy laws and intellectual property). Conversely, institutions are embedded within the products, actions, and perceptions of actors, and even knowledge and intelligent products can influence the formation or constraint of institutions. Institutions also regulate the conditions of actors' activities. Meanwhile, external factors (such as geopolitical shifts or social changes) are interpreted from within the innovation system, and their practical impact on the AI innovation system is determined (Bae & Kang, 2026; Guo & Liu, 2020; Sandén & Azar, 2005).

The research literature in the field of innovation systems highlights the non-linear nature of these systems, whereby their behavior is explained not by simple processes, but through complex dynamics, multiple feedback loops, and environmental interactions. To unravel this complexity, prominent scholars (Alkemade & Papachristos, 2025; Ille, 2022) have identified a set of "key processes" or "functions." The fulfillment of these functions is a prerequisite for achieving the system's ultimate goal: the development, diffusion, and successful utilization of technology.

At the infrastructural level, the two functions of "Knowledge Development and Diffusion" and "Resource Mobilization" serve as drivers. The expansion of the system's knowledge base (in AI domains) is realized through feasibility studies, market research, and networking, while "Resource Mobilization" undertakes the vital task of securing financial and human capital (such as R&D budgets and workforce training) (Ahmad, 2021).

The injection of these resources provides the operational foundation for "Entrepreneurial Experimentation," a function that mitigates initial risks through the exploration of novel applications and the execution of pilot projects. Simultaneously, the system requires "Influence on the Direction of Search" to align the activities of actors with macro priorities, utilizing levers such as regulation and incentives.

Ultimately, the fruition of innovation within the socio-economic context necessitates "Market Formation" (via standardization and demand stimulation) and "Legitimation" (social acceptance and institutional alignment). A mature innovation system operates beyond its own boundaries, resulting in the "Development of Positive Externalities," which manifests as knowledge spillovers and the formation of complementary infrastructures.

1. 1. 2 Conceptualization of Governance

In innovation governance studies, the scope of interventions is highly extensive, and researchers emphasize a spectrum of activities including symbolic actions, networking, public procurement, market guarantees, subsidies, and price stabilization in technological domains (Edquist et al., 2000; Faheem et al., 2026; Faturahman & Izra, 2025; Gouliaev & Senning, 1995; Ishizaki, 2000; Jacobsson, 2004; Jacobsson et al., 2004; Markard & Truffer, 2008; Rodríguez & Camacho, 2026;

Shelanski, 2004); second, "regulation," which encompasses executive interventions in socio-economic activities to realize public interests (*Handbook on the Politics of Regulation*, 2011; Levi-Faur, 2011); third, "facilitation," which focuses on empowerment and synergy among stakeholders; and fourth, "provisioning," which is tasked with providing goods and services for the welfare of stakeholders (Jakobsen, 2015; Jordana & Levi-Faur, 2004; Levi-Faur, 2011; Marsden, 1996; *The Politics of Regulation*, 2004; Scott, 2014).

The manner in which the aforementioned functions are implemented shapes the "governance style," which is distinguishable into at least four categories in the literature (Hillman et al., 2011). The regulatory style focuses on rule-making and standardization; in the market style, the modification and adjustment of economic incentives (such as taxes and subsidies) is central; the cognitive style centers on knowledge development, foresight, and consensus building, mirroring concepts of network governance; and finally, the normative style is characterized by development based on the values, beliefs, and preferences of society members (Kim, 2018; Shade, 2017).

To analyze governance arrangements more precisely, researchers have distinguished between three dimensions: "political," "policy," and "executive" (Kim, 2018). In this regard, a framework based on three key questions is presented that elucidates structural components and governance styles: 1) "Who governs?", which indicates the level of participation and coordination of actors; 2) "How is governance exercised?", which represents the governance style and the focus on supply or demand; and 3) "What is governed?", which indicates the objective of the innovation system and the characteristics of the technology (Hillman et al., 2011).

1.1.3 Literature Review and Identification of Research Gap

International and domestic studies indicate that prior research concerning the key concepts in this field, including "Artificial Intelligence (AI) Governance," the "AI Innovation System," and the "Governance of the Technological Innovation System (TIS)," has predominantly been conducted in a fragmented and independent manner. Nevertheless, the totality of these studies provides a comprehensive picture of the transformative dimensions of AI and the critical considerations required for developing innovation ecosystems. In the domain of innovation system governance, the prominent research by (Hillman et al., 2011) views governance arrangements as an external yet influential variable on the key processes of the innovation system, explicating it through three fundamental questions: "Who governs?", "How is governance exercised?", and "What is governed?". At the national level in Iran, Haji-Hosseini et al. (2011) have scrutinized the governance of the innovation system across the dimensions of "policy formulation," "design and implementation," and "evaluation and learning"(Haji-Hosseini et al., 2011).

AI is recognized as a pivotal driver of economic innovation. Research such as the work by Kao et al. (2019), utilizing multi-criteria decision-making methods, presented a model for evaluating systemic innovation performance, especially the factors influencing the industrial sustainability of AI in Taiwan's manufacturing sector (Kao et al., 2019). However, specialized AI applications in sectors like finance (using AutoML) improve predictive performance but face serious challenges regarding model interpretability and robustness, particularly during market crises, which limits their practical policy and regulatory adoption (Chen, 2025). From a governance perspective, rapid

innovations in AI challenge traditional regulatory regimes, necessitating the adoption of adaptive legal strategies to support innovation while concurrently addressing issues such as liability and algorithmic fairness (Wan et al., 2022). In this regard, the concept of AI governance (separate from a systemic approach) has also garnered attention from institutions such as the "European Union" (Alvarado, 2020; Wan, 2022), focusing on identifying areas requiring government intervention (such as ethics and security). Although some viewpoints (in line with Weber) assert that existing laws suffice, the prevailing view emphasizes the necessity of a comprehensive framework to cover stakeholder expectations (Steve, 2009; Weber, 2009; Weber & Studer, 2016).
Domestically in Iran, researchers such as Sadeghizadeh et al. (2019) adopted a field approach to analyze the functional aspects of AI as a technological innovation system within Iranian businesses (Sadeghizadeh et al., 2019). Similarly, Mousakhani et al. (2020), by modeling the functional dynamics, identified four primary focal points for policymakers: market formation, resource mobilization, entrepreneurial activities, and policy-making and coordination (Mousakhani et al., 2020). Concurrently, education and workforce development emerge as a key pillar, with research emphasizing the importance of creating new educational programs to build specialized capacity and strengthen national competitiveness (Bublyk & Roik, 2024; Chouhan & Chopra, 2025; Iurchenko, 2024). Management research further indicates that AI revolutionizes innovation management within organizations, necessitating frameworks for the responsible and strategic integration of AI systems (Akman, 2025; Shahmerdanova, 2025). Additionally, sector-specific studies confirm AI's role in medicine (intelligent diagnostics) (Sadriwala et al., 2024) and marketing innovation (Shahmerdanova, 2025). A visual representation of the research gap and theoretical contribution was shown in Fig. 1.

Fig. 1. Visual Representation of the Research Gap and Theoretical Contribution.

Ultimately, comprehensive domestic and international research emphasizes that AI innovation systems are multifaceted and require collaborative and adaptive governance and capacity building for the responsible and sustainable exploitation of AI's full innovative potential. However, the existing literature possesses two major limitations that the present research seeks to address: Firstly, the origin of most studies is in developed countries, focusing on non-digital technologies, and governance is merely considered a component of system functions. Secondly, the precise elucidation of the reciprocal relationship between "governance functions" and "Technological Innovation System functions" has been neglected. This theoretical gap constitutes a serious challenge for developing countries like Iran facing the accelerating wave of digital technologies. Therefore, the present research endeavors to fill this void and present a localized model by focusing on the AI ecosystem in Iran—which is in dire need of a governance pattern—with the aim of elucidating the role of governance in the development of the Artificial Intelligence Technological Innovation System.

2. Methods

In terms of objective, the current research is applied, and regarding methodology, it falls within the category of qualitative and descriptive-survey studies. It was conducted with the aim of exploring interactions among variables and describing the role of governance in the Artificial Intelligence Technological Innovation System. In this process, roles and activities were initially identified through documentary research and a review of organizational documents and mandates. Subsequently, the seven-function model (Bergek, 2008) served as the basis for historical analysis and event mapping, taking into account the nature of Artificial Intelligence and its knowledge spillovers (such as Big Data and the Internet of Things). The statistical population comprised actors within the innovation system. In-depth interviews were conducted with representatives from its structural components, including 6 individuals from the actors sector, 5 from institutions, 5 from the network sector, and 4 from knowledge and product providers.

Regarding sample selection, given that the details of the governance role were initially unclear, the snowball sampling method was employed. This process commenced with interviews with three prominent figures from academia, industry, and government, and continued until data saturation was achieved. In certain instances, social networks were also utilized for "virtual snowball sampling." Concurrent with data collection, manifest and latent content analysis of the interviews was conducted to explore the relationship between governance and the seven functions. In this process, based on Gillham's (2000) approach, key propositions were identified and categorized under main and sub-categories through two stages of open and axial coding.

Finally, to evaluate the quality of the results, the "trustworthiness" index, encompassing four main criteria, was utilized instead of quantitative validity and reliability measures. To ensure "credibility," strategies such as reputation-based sampling, interviewee feedback, and the use of direct descriptors (quotations) were employed. To guarantee "transferability," interviewees were selected from reputable senior managers, and a detailed description of the research specifics was provided. Furthermore, to ensure "dependability," data and methods were made available to other researchers for auditing, and for "confirmability," the full details of the analysis process and selected interview excerpts were presented. The research methodology process is shown in Fig. 2.

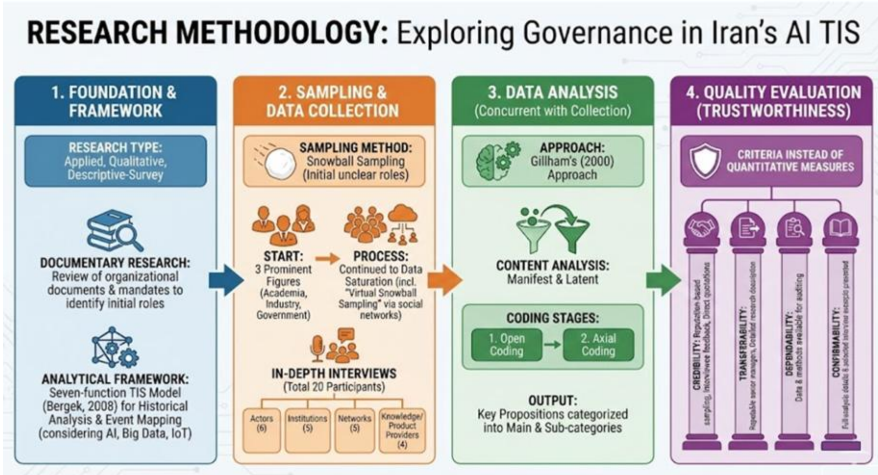

Fig. 2. Research Methodology Flowchart.

3. Results

3.1. Comprehensive Analysis and Systemic Pathology of the Artificial Intelligence Ecosystem in Iran (2015–2025)

The Information and Communication Technology (ICT) ecosystem in Iran has experienced a tumultuous transition over the past decade (2015–2025), evolving from a purely academic subject into an inevitable necessity for national security and economic survival. This era, which commenced with hopes stemming from international openings and concluded with the age of "Generative AI" and efforts to establish national data sovereignty, necessitates an analysis beyond mere chronology. In this regard, utilizing the "Technological Innovation Systems" (TIS) framework facilitates the investigation of complex dynamics among actors and institutions. The fundamental hypothesis of this analysis indicates that although Iran has reached relative maturity in the functions of "Knowledge Development" and "Legitimation," "Resource Mobilization" and "Market Formation" continue to act as systemic bottlenecks, preventing the complete transformation of scientific potential into economic value added.

In examining the function of legitimation, a process has been observed that began with the intervention of high-level governance and a discourse shift from a luxury topic to a "civilizational driver." This change in approach led to the breaking of bureaucratic resistance barriers and the allocation of initial budgets; however, at the executive level, it faced institutional challenges and structural uncertainty. The establishment of the "National Artificial Intelligence Organization" and its subsequent transformation into a "Headquarters," although intended to enhance agility, created fluctuations in governance stability. Nevertheless, the approval of the "National Artificial Intelligence Document" in 2024, with ambitious quantitative goals such as achieving the 15th global rank in science production and developing 2,000 indigenous products, served as a turning point in legal legitimation. In the international and ethical dimensions, events such as the Mustafa Prize and the formulation of ethical principles contributed to strengthening scientific standing and managing social concerns regarding this technology, respectively.

The function of influence on the direction of research underwent fundamental changes during this decade under the influence of two factors: "sanctions pressure" and the "emergence of generative artificial intelligence." Academic research, initially focused on classical algorithms, was directed toward solving industrial challenges such as machine vision for surveillance and banking data mining. With the introduction of ChatGPT, the research trajectory shifted sharply toward Natural Language Processing (NLP) and the development of indigenous language models such as "Dorna," "Silk," and "Ava" to prevent linguistic colonialism. Simultaneously, the convergence of artificial intelligence with core industries and the Internet of Things (IoT) in companies such as Mobarakeh Steel steered research from the laboratory to production lines and predictive maintenance, which had a direct impact on national productivity.

In the domain of knowledge development and diffusion, Iran faces a paradox of high scientific production (ranking second in the region) versus the challenge of effective diffusion and commercialization. The country's top-tier universities have played the role of the driving engine for knowledge production, yet a weakness in industry-university collaboration is evident. Despite this, events such as the ICSPIS conference and the Rayan Artificial Intelligence Contest have functioned as vital arteries for knowledge circulation. In the non-formal education sector, the private sector, by organizing project-based courses in centers such as DigiNext and Part, has shouldered the main burden of training a skilled workforce and bridging the skill gap between the university and the labor market.

Entrepreneurial experimentation in this ecosystem has evolved from a phase of imitating global models to indigenous innovation and Deep Tech. Initially, large platforms such as Digikala and Snapp, utilizing massive user data, implemented artificial intelligence in logistics and dynamic pricing. In the second half of the decade, companies such as "Part," through the development of biometric authentication services and natural language processing, and specialized startups in the fields of health and smart agriculture, demonstrated that the ecosystem has attained the necessary technical maturity to offer complex and technology-based solutions.

However, the function of resource mobilization faces serious crises in infrastructure and human capital, serving as the system's Achilles' heel. The strategic hardware gap resulting from sanctions and the inability to procure advanced graphics processing units (GPUs) has halted projects such as the Maryam supercomputer and increased the distance between Iran and the global technological edge. Simultaneously, the phenomenon of brain drain and the emigration of elites due to economic difficulties has depleted the ecosystem of senior forces. In response to the shortage of traditional venture capital, the emergence of Corporate Venture Capital (CVC) funds in large industries and support from the Innovation and Prosperity Fund have attempted to partially compensate for the financial resource vacuum.

In the function of market formation, the government has been the largest driver of demand by defining national macro-projects and mandating device smartization, although bureaucratic challenges have reduced the attractiveness of this market. In the private sector, the banking industry (Fintech) and core industries have been the leading applicants for artificial intelligence. Despite the growth of the domestic market, severe restrictions on the export of technological products due to banking sanctions have hindered the international scalability of companies, although cooperation with BRICS member countries has opened some windows of opportunity. Finally, the positive externalities of this technology in preserving the Persian language, enhancing agricultural productivity and industrial safety, and increasing public digital literacy indicate the penetration of artificial intelligence into the depth of the country's cultural and social structures.

For the future, the policy-maker's focus must shift from document drafting toward facilitation in infrastructure provision and stimulation of private sector demand.
In the following, analytical explanations and guidelines are provided to facilitate a deeper understanding of each of the two presented tables. These explanations will assist in better interpreting the logic governing the Technological Innovation Systems (TIS) analysis and the status of Iran's artificial intelligence ecosystem. Following these explanations, both tables are presented in a fully codified manner.

Part 1: Analysis and Interpretation of Tables

1. Analysis of the Functional Status Summary in Table 1
This table functions as a "managerial dashboard" for policymakers, depicting the overall health of the system at a glance.

- **Color-Coding Logic:** A traffic light system (Green, Yellow, Red) has been utilized to delineate intervention priorities.
- **Strengths (Green):** As indicated in the analyses, Iran has performed beyond expectations in "Knowledge Development" (Science Production) and "Discourse Formation" (Legitimation). This demonstrates that the academic and governance bodies have effectively fulfilled their duties at the theoretical and legal levels.
- **Warning Points (Yellow):** The status of "Entrepreneurial Experimentation" and "Market Formation" is in an intermediate state. Although startups have emerged, they have not yet reached full maturity or global markets due to economic limitations and sanctions.
- **Critical Points (Red):** The "Resource Mobilization" function has been identified as the primary bottleneck. This serves as a warning that all scientific achievements (Green section) are at risk of attrition or emigration in the absence of hardware and capital (Red section).

2. Analysis of the Event-Function Alignment Matrix in Table 2
This table illustrates the "impact mechanism" of events and specifies which part of the system each action has stimulated.

- **Government Focus:** Observing the table reveals that government actions (documents, organizations) have predominantly filled the columns of "Legitimation" and "Guidance of the Search." This implies that the government has appeared more in the role of a "policymaker" rather than a "provider."
- **Role of the Private Sector:** Events related to the private sector (such as DigiNext or Mobarakeh Steel) have primarily activated the columns of "Entrepreneurial Experimentation" and "Market Formation."
- **System Gaps:** Empty cells in the table indicate areas where insufficient events have occurred to cover them. For instance, the lack of effective events in the "Resource Mobilization" column (with the exception of the Simorgh inauguration, which was insufficient) confirms the critical nature of this function.

Part 2: Codified Tables of Iran's Artificial Intelligence Ecosystem

Table 1.
Comparative Summary of the Functional Status of the AI Innovation System (2015–2025).

TIS Function	Key Events (2015–2025)	Performance Status and Pathology
1. Legitimation	Establishment and structural change of the responsible body (National AI Organization/Headquarters), notification of the National Document in 2024, awarding of the Mustafa Prize	🟢 Matured Successful in governance discourse formation, but facing challenges regarding structural fluctuations in execution.
2. Guidance of the Search	Pivot of research toward indigenous Large Language Models (LLMs), industry focus on smartening production lines (Steel)	🟢 Responsive and Transparent Rapid adaptation of the research trajectory to industrial needs and linguistic/security threats.
3. Knowledge Development	Achieving high scientific rank in the region, continuous holding of specialized conferences (ICSPIS), Rayan scientific competitions	🟢 Strong and Stable Desirable science production, but with the risk of declining quality and lack of connection to industry.
4. Entrepreneurial Experimentation	Formation of innovation ecosystems in large companies (DigiNext, Snapp), development of Deep Tech products (Part)	🟡 Growing Transitioning from imitation to innovation, but limited to the domestic market and under pressure from team emigration.
5. Resource Mobilization	Inauguration of the Simorgh supercomputer, halting of development projects (Maryam), elite migration crisis, entry of CVCs	🔴 Critical (System Bottleneck) Severe hardware poverty (GPU) and human capital shortage; threatening all system achievements.
6. Market Formation	$25 billion ICT market, high demand in Fintech and core industries, e-government projects	🟡 Moderate Heavy reliance on government demand and large industries; severe weakness in export markets.
7. Positive Externalities	Development of Persian language processing infrastructures, increased productivity in agriculture and industry, promotion of digital literacy	🟢 Positive and Increasing Creation of soft and cultural infrastructures operating beyond the economic profit of firms.

Table 2.

Alignment Matrix of Key Events and Activities with the Seven TIS Functions.

Key Event / Activity	Legitimation	Guidance of the Search (Research Path)	Knowledge Development & Diffusion	Entrepreneurial Experimentation	Resource Mobilization	Market Formation	Positive Externalities
A) Governance Documents and Institutions							
Establishment of the National AI Organization (2024)	*	*					
Notification of the National AI Document (Supreme Council	*	*			*	*	

Key Event / Activity	Legitimation	Guidance of the Search (Research Path)	Knowledge Development & Diffusion	Entrepreneurial Experimentation	Resource Mobilization	Market Formation	Positive Externalities
of the Cultural Revolution)							
Formulation of AI Ethical Principles (ICT Research Institute)	*						*
B) Infrastructure and National Projects							
Inauguration of the Simorgh Supercomputer (Amirkabir University - 2021)					*		*
Indigenous Large Language Model Development Project (Dorna, Silk, Ava)		*	*				*
Mandating agencies to smarten 20% of services (Smart Government)						*	
C) Networks and Scientific/Promotional Events							
The Mustafa Prize	*		*				
International Conference on Intelligent Systems (ICSPIS)		*	*				
Rayan AI Contest and Sharif Cup			*	*			
D) Private Sector and Industry Actors							
Activity of DigiNext Innovation Center and Venture Capital				*			

Key Event / Activity	Legitimation	Guidance of the Search (Research Path)	Knowledge Development & Diffusion	Entrepreneurial Experimentation	Resource Mobilization	Market Formation	Positive Externalities
Smartening in Core Industries (Mobarakeh Steel, Oil)		*			*	*	*
Development of Authentication and Text Processing Services (Part Company)				*		*	

3.2. Qualitative Data Analysis: The Role of Governance in the AI Innovation System

The practical process of qualitative data analysis of the interviews was conducted in four stages: data preparation, familiarization, coding, and generating meanings and concepts. To exploratively examine the interviewees' perspectives, common concepts of Technological Innovation System (TIS) functions, with a special emphasis on those more closely related to the four governance functions (policy-making, regulation, facilitation, and service provision), were established as the criteria for initiating and organizing the interviews. At this stage, a code from I_1 to I_{20} was assigned to each interviewee. In open coding, key concepts and propositions from AI managers and experts were categorized as indicators representing each function. In axial coding, these were categorized under TIS functions, and in the selective coding stage, a common title was assigned to a set of TIS functions most relevant to governance.

The analysis of qualitative data and the output of coding stages regarding the relationship between the **policy-making** function of governance and the functions of the AI technological innovation system are presented in Table 3. As can be observed, policy-making has had the most significant relationship with "influence on the direction of search" (through upstream documents) and "market formation" (through government mandates).

Table 3.

Coding results of the policy-making function in relation to key TIS processes (AI Ecosystem).

Selective Code	Axial Codes	Open Codes	Frequency	Interviewee Code
Policy-making	Knowledge Development and Diffusion	Prioritizing data science and AI in universities	13	$I_{1-3}, I_{5-6}, I_8, I_{12-14}, I_{17}, I_{19-20}$
		National needs assessment for developing indigenous language models	12	$I_1, I_4, I_6, I_{8-10}, I_{15-16}, I_{18-20}$
	Entrepreneurial Experimentation	Incentive policies for Deep Tech companies	14	$I_{3-7}, I_{9-15}, I_{20}$

Selective Code	Axial Codes	Open Codes	Frequency	Interviewee Code
	Influence on the Direction of Search	Macro-targeting (Ranking 15th globally and National AI Document)	17	$I_{2-11}, I_{13-18}, I_{20}$
		Determining strategic priorities (e.g., Generative AI)	15	$I_{1-2}, I_{4-5}, I_{7-9}, I_{11-13}, I_{15-19}$
	Market Formation	Mandating agencies to smarten services (20% smart services law)	16	$I_{1}, I_{3-11}, I_{13-15}, I_{18-20}$
	Resource Mobilization	Planning to prevent the brain drain of AI elites	15	$I_{2-3}, I_{5-8}, I_{10-17}, I_{19}$

The coding results regarding the relationship between the regulation function of governance and the functions of the AI technological innovation system are presented in Table 4. According to the interviewees, regulatory roles have primarily focused on "legitimation" (through ethical principles) and "market formation" (data standardization).

Table 4.

Coding results of the regulation function in relation to key TIS processes (AI Ecosystem).

Selective Code	Axial Codes	Open Codes	Frequency	Interviewee Code
Regulation	Influence on the Direction of Search	Directing towards ethics-centered and safe research	15	$I_{1-2}, I_{4-10}, I_{13-18}$
	Market Formation	Formulating data ownership and privacy regulations	16	$I_{2-5}, I_{7-10}, I_{12}, I_{14}, I_{16-20}$
		Standardization of smart software products	17	$I_{1-4}, I_{6-13}, I_{15-19}$
	Resource Mobilization	Monitoring the allocation of research budgets	14	$I_{1-4}, I_{8-11}, I_{13-14}, I_{16-19}$
	Legitimation	Formulating AI ethical principles	15	$I_{2-4}, I_{6}, I_{9-13}, I_{16}, I_{18-20}$
		Risk management and social acceptance of technology	13	$I_{5-8}, I_{10-12}, I_{14-17}, I_{19-20}$

The coding results regarding the relationship between the facilitation function of governance and innovation system functions in Table 5 indicate a broad relationship between this function and processes such as "knowledge development" (events) and "entrepreneurial experimentation" (innovation centers).

Table 5.

Coding results of the facilitation function in relation to key TIS processes (AI Ecosystem).

Selective Code	Axial Codes	Open Codes	Frequency	Interviewee Code
Facilitation	Knowledge Development and Diffusion	Organizing scientific competitions (e.g., Rayan Prize and Sharif Cup)	**16**	$I_{1}, I_{3-5}, I_{7-10}, I_{12-13}, I_{15-20}$

Selective Code	Axial Codes	Open Codes	Frequency	Interviewee Code
		Supporting specialized conferences (ICSPIS)	**14**	$I_{1-2}, I_{4-7}, I_{10-12}, I_{14-17}$
		Promoting science and technology discourse (Mustafa Prize)	**15**	$I_{1-3}, I_{5-6}, I_{8-10}, I_{12-16}, I_{19-20}$
	Entrepreneurial Experimentation	Supporting accelerators (e.g., DigiNext)	**16**	$I_{1-3}, I_5, I_{7-10}, I_{12-13}, I_{15-20}$
		Facilitating company entry into science and technology parks	**15**	$I_{2-5}, I_7, I_{9-10}, I_{12}, I_{14-20}$
	Resource Mobilization	Facilitating venture capital attraction (CVCs)	**17**	$I_{1-2}, I_{4-5}, I_{7-11}, I_{13-20}$
		Networking between domestic and international elites	**14**	$I_2, I_{5-8}, I_{10-11}, I_{14-16}, I_{19-20}$
	Development of Positive Externalities	Developing soft infrastructure (Persian open data)	**15**	$I_{1-2}, I_{4-7}, I_9, I_{11-12}, I_{14-16}, I_{18}$

The coding results for the relationship of the service provision (provision/supply) function of governance with key processes are presented in Table 6. This function has played a vital role, particularly in "resource mobilization" (computing infrastructure) and "development of positive externalities" (preservation of the Persian language).

Table 6.

Coding results of the service provision function in relation to key TIS processes (AI Ecosystem).

Selective Code	Axial Codes	Open Codes	Frequency	Interviewee Code
	Knowledge Development and Diffusion	Providing massive training data (Corpus)	**16**	$I_1, I_{3-5}, I_{7-10}, I_{12-18}, I_{20}$
		Direct investment in computing infrastructure (Simorgh supercomputer)	**18**	$I_{1-5}, I_{7-12}, I_{14-16}, I_{18-20}$
	Resource Mobilization	Providing research grants and non-repayable loans	**15**	$I_{2-7}, I_9, I_{11-13}, I_{15-16}, I_{18-20}$
Service Provision		Providing currency for hardware imports (GPU)	**17**	$I_1, I_2, I_{5-11}, I_{13-15}, I_{17-20}$
	Market Formation	Government procurement (e-government projects)	**16**	$I_{1-6}, I_{8-10}, I_{12-16}, I_{18-20}$
		Subsidies for implementing AI in industries	**14**	$I_{1-8}, I_{10}, I_{12-15}, I_{19}$
	Development of Positive Externalities	Developing foundation language models (public infrastructure)	**17**	$I_{1-5}, I_{7-12}, I_{14-17}, I_{19-20}$
		AI-based cyber and defense security	**15**	$I_{2-4}, I_{6-12}, I_{15-18}$

4. Discussion & Conclusions

The analysis of qualitative data derived from interviews ($I_1 - I_{20}$) reveals a distinct structural coupling between governance functions and the functional dynamics of the Artificial Intelligence TIS in Iran. Contrary to the fragmented approach observed in earlier stages of digital technology adoption, the findings suggest that the governance of AI in Iran is evolving toward a more structured, albeit uneven, intervention model. The following sections interpret these relationships based on the four key governance functions.

4.1. Policy-making: Normative Direction and Demand Stimulation

The results from Table 3 indicate that the policy-making function is most strongly correlated with "Influence on the Direction of Search" and "Market Formation". The high frequency of codes related to macro-targeting (e.g., the National AI Document) suggests that the state acts as the primary architect of the technological trajectory. By setting ambitious goals (e.g., global ranking 15th), the governance system attempts to reduce uncertainty for actors, a critical requirement for emerging TIS. Furthermore, the strong link to "Market Formation" through mandates (e.g., the 20% smart services law) highlights a top-down strategy to create initial demand for AI products, compensating for the immaturity of the private B2B market.

4.2. Regulation: Legitimation and Standardization

As detailed in Table 4, the regulatory function plays a pivotal role in "Legitimation" and "Market Formation". The emphasis on AI ethical principles and data privacy regulations indicates that the governance system recognizes the social risks associated with AI. By establishing these frameworks, the state aims to build social acceptance (Legitimation), which is a prerequisite for widespread adoption. Additionally, the focus on standardization serves to unify the fragmented market, ensuring that AI software products are interoperable and meet minimum quality thresholds, thereby reducing transaction costs for potential adopters.

4.3. Facilitation: Knowledge Diffusion and Ecosystem Building

The findings in Table 5 demonstrate that the facilitation function is broadly distributed across "Knowledge Development" and "Entrepreneurial Experimentation". The high frequency of codes related to scientific competitions and accelerator support suggests that the government is actively trying to bridge the gap between academic research and commercial application. Unlike the restrictive nature of regulation, facilitation in this context acts as a catalyst, focusing on "soft" infrastructure such as networking and human capital development. This aligns with the "cognitive" style of governance, where the focus is on learning and consensus-building among actors.

4.4. Service Provision: Addressing Systemic Bottlenecks

Perhaps the most critical finding, shown in Table 6, is the dominant role of the service provision (supply) function in "Resource Mobilization" and "Development of Positive Externalities". The explicit mention of direct investment in computing infrastructure (e.g., the Simorgh supercomputer) and providing currency for hardware imports reveals that the governance system is stepping in to address a market failure. Due to international sanctions and high capital costs, the private sector is unable to mobilize sufficient resources for high-performance computing (HPC). Consequently, the state has assumed the role of the primary provider of "hard" infrastructure. This intervention is essential for generating positive externalities, such as the preservation of the Persian language through state-funded Large Language Models (LLMs), which private firms might deem unprofitable.

4.5. General Conclusion

The systemic pathology of the AI ecosystem in Iran (2015–2025) indicates a transition from a "laissez-faire" approach to a "developmental state" model in the digital sector. While the system has achieved maturity in Knowledge Development and Legitimation through effective policy-making and regulation, it faces a critical bottleneck in Resource Mobilization. The heavy reliance on the government's Service Provision function to supply hardware and funding highlights the fragility of the private sector.

To ensure the sustainability of the AI TIS, future governance strategies must shift from direct provision to enabling private resource mobilization. This entails optimizing the regulatory environment to attract Venture Capital (VC) and leveraging "Facilitation" to connect domestic capabilities with international networks (e.g., BRICS), thereby reducing the system's vulnerability to external shocks and internal resource constraints.

Based on the qualitative analysis of the Iranian AI ecosystem (2015–2025) and the theoretical framework from the provided text, here is the comparative summary Table 7.

Table 7.

Impact of Governance Functions on AI Technological Innovation System (TIS).

Governance Function	Primary TIS Functions Impacted	Key Interventions & Mechanisms	Systemic Effect on AI Ecosystem
1. Policy-making	• Influence on the Direction of Search • Market Formation	• Setting macro-targets (e.g., National AI Document, top 15 global rank). • Mandating government agencies to smarten 20% of services. • Prioritizing data science in university curricula.	Reduces Uncertainty: Acts as the strategic architect, signaling long-term commitment to actors and creating initial B2G demand to de-risk investment.
2. Regulation	• Legitimation • Market Formation	• Formulating AI ethical principles and safety guidelines. • Establishing data privacy and ownership regulations. • Standardizing software products to ensure interoperability.	Builds Trust: Manages social risks and builds the necessary legal/ethical framework for widespread adoption, preventing market fragmentation.

Governance Function	Primary TIS Functions Impacted	Key Interventions & Mechanisms	Systemic Effect on AI Ecosystem
3. Facilitation	• Knowledge Development & Diffusion • Entrepreneurial Experimentation	• Organizing scientific competitions (e.g., Rayan Prize) and conferences. • Supporting accelerators (e.g., DigiNext) and innovation centers. • Networking between domestic elites and international experts.	Catalyzes Flows: Bridges the gap between academic research and industrial application by fostering soft infrastructure and human capital development.
4. Service Provision *(Supply)*	• Resource Mobilization • Development of Positive Externalities	• Direct investment in hard infrastructure (e.g., Simorgh Supercomputer). • Providing currency/grants for GPU imports. • Funding public goods like indigenous Large Language Models (LLMs).	Compensates for Market Failure: Steps in where the private sector cannot (due to sanctions or high costs), ensuring the existence of critical infrastructure and cultural preservation (Persian language).

The role of governance in Iran's AI innovation system is shown in Fig. 3.

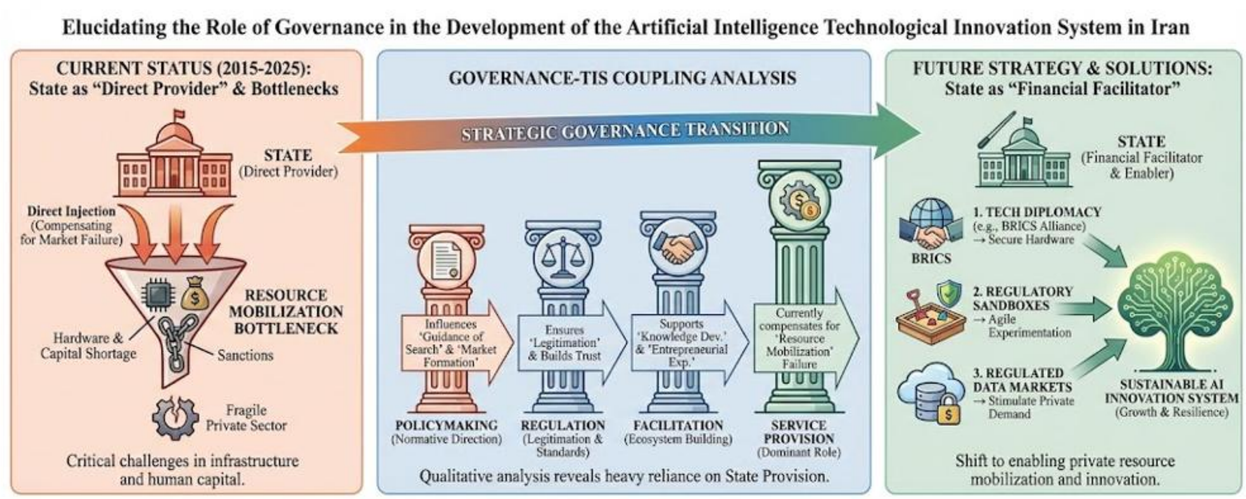

Fig. 3. The Role of Governance in Iran's AI Innovation System.

4.6. Implications for Non-Iranian Contexts and the Global South

While this study focuses on Iran, the proposed transition from a "Service Provider" to a "Financial Facilitator" state offers a blueprint for other developing economies facing the "middle-income trap" in the digital era. Specifically, nations in the Global South that grapple with limited access to high-end hardware (due to economic constraints or geopolitical barriers) and "brain drain" can utilize the proposed model. The strategy of leveraging "Technology Diplomacy" (e.g., via BRICS or regional alliances) and establishing "Regulatory Sandboxes" is not unique to Iran; it serves as a universal mechanism for latecomer countries to bypass traditional industrialization phases and enter the AI economy without relying solely on Western technology stacks. Thus, this governance model contributes to the broader literature on TIS in constrained environments.

4.7. Policy Recommendations

Based on the pathology of the Iranian AI ecosystem and the dominant role of the state in "Service Provision," several policy recommendations are proposed to enhance the sustainability and efficiency of the Technological Innovation System (TIS). First, the government must transition from a "Direct Provider" of hardware to a "Financial Facilitator" by gradually reducing direct procurement and instead establishing matching funds and state guarantees to incentivize private resource mobilization. Second, for Iran and similar developing nations subject to technological restrictions, the facilitation function should prioritize technology diplomacy. By leveraging regional alliances like BRICS and SCO to define joint R&D projects and secure parallel supply chains, these nations can mitigate hardware constraints exacerbated by sanctions or global market monopolies. Furthermore, to stimulate market formation and private demand, policymakers should focus on "Data Liberation" by implementing Open Data protocols and creating regulated Data Marketplaces, thereby allowing startups to access essential training data without prohibitive costs. Finally, to prevent strict regulations from stifling entrepreneurial experimentation, an agile regulatory approach is necessary; this involves establishing "Regulatory Sandboxes" where innovators can test emerging AI applications, such as autonomous vehicles, on a limited scale under supervision but free from complex bureaucratic hurdles .

4.8. Model Description

This Fig. 4 illustrates the conceptual model of the transition from the current state to the desired state in AI governance. The Old State-Centric Model on the left depicts the current status as a rigid, static concrete structure constrained by "Sanctions" (symbolized by chains), where a "Resource Mobilization Bottleneck" funnel at the top illustrates the severely restricted inflow of hardware and capital, resulting in a "Fragile Private Sector" represented by a small, weak gear . In the center, a flowing, luminous arrow marks the Strategic Governance Transition, representing the process of "Shifting the Role" of the state from a direct provider to a "Facilitator". Finally, the New Facilitative Ecosystem on the right visualizes the desired future state as an organic, dynamic, and interconnected network where innovation flow is enabled through three key mechanisms: Tech Diplomacy (e.g., the BRICS Alliance) for secure hardware supply, Regulatory Sandboxes for agile and innovative experimentation, and Regulated Data Markets to stimulate private sector demand, ultimately achieving a "Sustainable AI Innovation System" characterized by growth and resilience.

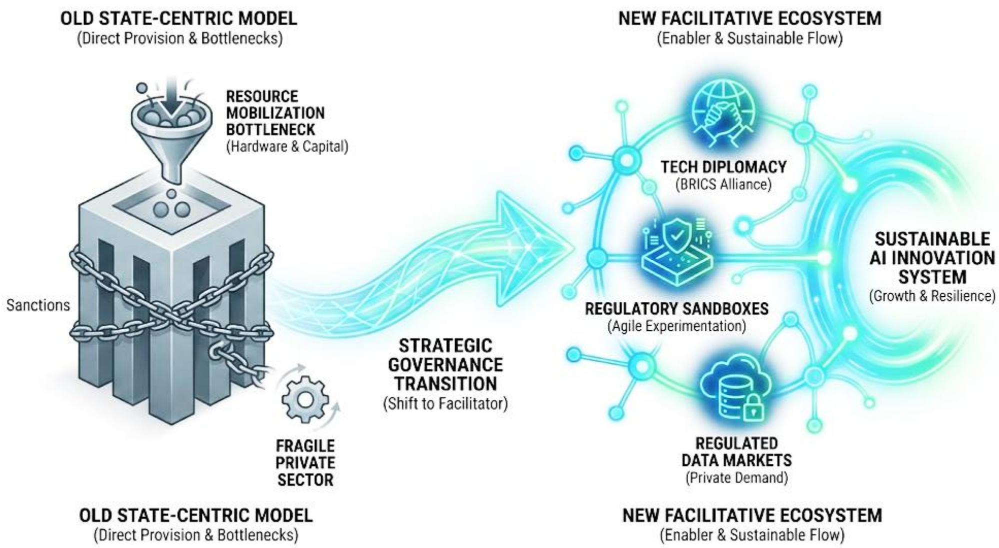

Fig. 4. Conceptual Framework of Strategic Governance Transition.

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Conflicts of interest

The authors declare no conflict of interest.

Authors contribution statement

Seyed Rasool Anbarzadeh, Shahram Aliyari: Conceptualization; Seyed Rasool Anbarzadeh, Shahram Aliyari: Data curation; Seyed Rasool Anbarzadeh: Formal analysis; Seyed Rasool Anbarzadeh, Shahram Aliyari: Investigation; Seyed Rasool Anbarzadeh, Shahram Aliyari: Methodology; Seyed Rasool Anbarzadeh: Project administration; Seyed Rasool Anbarzadeh: Resources; Seyed Rasool Anbarzadeh: Software; Seyed Rasool Anbarzadeh: Supervision; Seyed Rasool Anbarzadeh, Shahram Aliyari: Validation; Seyed Rasool Anbarzadeh, Shahram Aliyari: Visualization; Seyed Rasool Anbarzadeh, Shahram Aliyari: Roles/Writing – original draft; Seyed Rasool Anbarzadeh, Shahram Aliyari: Writing – review & editing.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. The raw interview data are not publicly available due to privacy and ethical restrictions regarding the anonymity of the participants.

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